REMARKS:

The present Amendment makes editorial changes in the specification, drawings, claims and Abstract to conform the present PCT application to the requirements of United States patent practice. The cancellation of claims 1-

5   26 in favor of the claims presented herein has been undertaken solely because the amount of strikethroughs and underlining that would have been necessary to confirm original claims to the requirements of 35 U.S.C. §112, second paragraph would have been unduly burdensome and confusing. No change in the claim language has been made for the purpose of

10   distinguishing any claim over the teachings of the prior art of record. Accordingly, no change in the claim language is considered by the Applicant as a surrender of any of the subject matter encompassed within the scope of original claims 1-26.

Early consideration of the application is therefore respectfully

15   requested.

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CH1\ 4376237.1

IN THE DRAWINGS:

Figures 1a, 1b and 2 have been amended as shown on the replacement sheets attached hereto.

S P E C I F I C A T I O N

TITLE

"DETECTION OF DIASTOLIC HEART FAILURE"

BACKGROUND OF THE INVENTION

5 ~~Technical Field~~

Field of the Invention

The present invention relates to an implantable medical apparatus for detecting diastolic heart failure~~, DHF, comprising~~ (DHF), of the type having a DHF determining device for determining at least one blood pressure

10 parameter for detecting a DHF state of the heart of a patient. The invention also relates to a pacemaker provided with such an apparatus, and a method of detecting DHF, ~~comprising~~ including the step of determining at least one blood pressure parameter for detecting a DHF state of the heart of a patient.

~~Background~~

15 ### Description of the Prior Art

There is a growing recognition that congestive heart failure caused by a predominant abnormality in the diastolic function, i.e. diastolic heart failure, DHF, is both common and causes significant morbidity and mortality. Therefore early detection of DHF is important. Patients do not, however,

20 seem to have symptoms at an early stage. In addition it has been hard to separate diastolic and systolic heart failure and they may also exist simultaneously.

It has been discovered that among the few parameters, separating diastolic heart failure from systolic heart failure, are certain blood pressure

25 parameters obtained during work of the patient. Thus ~~US 6 438 408~~ United States Patent No. 6,438,408 describes an implantable medical device for monitoring congestive heart failure, CHF. A ~~plurality~~ number of heart failure parameters indicative of the state of the heart failure are measured employing EGMs, blood pressures including absolute pressures, developed pressures

30 (= systolic pressures − diastolic pressures) and the time derivative dP/dt, as

well as heart chamber volumes. One of these parameters is the relaxation or contraction time constant τ of the heart chamber. <u>This constant</u> τ is calculated from a continuous pressure signal and is the drop in ventricular pressure at the end of systole and in the first part of diastole. The τ

5   parameter is thus a general parameter reflecting the relaxation process.

Patients suffering from DHF have both elevated ventricular filling pressure and elevated pulmonary venous pressure. To maintain cardiac output under load higher filling pressures are required to achieve adequate left ventricular filling, see H. Weinberger, Diagnosis and Treatment of Diastolic

10   Heart   Failure,   Hospital   Practice, http://www.hosppract.com/issues/1999/03/weinb.htm.   However, for DHF patients increased filling pressure does not result in increased left ventricular diastolic volymes. This is illustrated in figure 1 which shows results of studies on patients with isolated diastolic dysfunction, see D. W. Kitzman et al,

15   "Exercise Intolerance in Patients with Heart Failure and Preserved Left Ventricular Systolic Function: Failure of the Frank-Starling Mechanism", J. Am. Coll. Cardiol., 17:1065-1072, 1991. Figure 1a shows the pulmonary capillary wedge pressure, PCWP, as a function of workload for patients with isolated diastolic dysfunction and for control persons not suffering for this

20   dysfunction, and figure 1b shows corresponding curves for the left ventricular end-diastolic volume index, LVEDVI as a function of the workload. From the figures it appears that for patients suffering from the mentioned diastolic dysfunction, PCWP was elevated at rest and further elevated during exercise. This indicates that the ventricular filling pressure was increased under both

25   conditions, whereas LVEDVI did not increase with exercise.

SUMMARY OF THE INVENTION

~~The~~ <u>An object of the</u> present invention is ~~based on the above mentioned knowledge. The purpose of the present invention is consequently~~ to utilize ~~this teaching to propose~~ <u>the above information to provide</u> a technique

30   for detecting DHF based on measurement of left atrial or pulmonary vein pressure.

~~Disclosure of the Invention~~

~~This purpose is obtained by an apparatus, a pacemaker and a method of the kind mentioned in the introductory portion of the description and having the characterizing features of claims 1, 2, 12, 16 and 17 respectively.~~

5

Thus with the present invention the reduced peak and submaximal exercise performance of DHF patients ~~is~~ <u>are</u> utilized for detecting DHF. With a sensor placed in left atrium or very close to ~~its~~ <u>the</u> endocardium <u>thereof,</u> the left atrial pressure is measured during the diastasis phase just before atrial

10   contraction. Alternatively a sensor in the pulmonary vein can be used, provided that pressure data for subsequent analysis are collected only when the pulmonary valve is closed. With the technique according to the invention it is possible to detect DHF at an early stage, often before the patient seems to have any symptoms.

15   In the present invention the workload situation of the patient must be identified, and therefore, ~~according to~~ <u>in</u> an ~~advantageous~~ embodiment of the apparatus according to the invention, an activity sensor is provided for determining the workload of the patient.

Since the absolute pressure is used, measured pressure values must

20   be corrected with e.g. the level of the mean pressure in the right atrium or in vena cava close to the right atrium. This correction is needed because any column of blood above the sensor location, which thus is posture depending, will add to the absolute pressure level. Such a correction will also compensate for a varying ambient pressure. ~~According to~~ <u>In</u> an

25   ~~advantageous~~ embodiment of the apparatus according to the invention <u>a</u> pressure ~~compensating means are~~ <u>compensator is</u> therefore provided for correcting the measured absolute value of left atrial pressure with the mean <u>(average)</u> pressure in right atrium or in vena cava close to the right atrium.

~~According to~~ <u>In</u> another ~~advantageous~~ embodiment of the apparatus

30   according to the invention<u>,</u> the DHF determining device ~~comprises~~ <u>includes</u> an impedance measuring ~~means~~ <u>unit</u> for measuring the impedance between a left ventricular electrode and a second electrode intended to be positioned ~~in~~

~~such a place~~ at a location so that most of variations in the measured impedance are due to varying left ventricular volume~~, and in that~~ . ∆P values and corresponding values of the difference, ∆V, in the end-diastolic ventricular volume, obtained from ~~said~~ the impedances measured for ~~said~~ the predetermined workload situation and for the patient in rest, are supplied to a quotient forming ~~means~~ unit to form the quotient ∆P/∆V, and ~~in that said comparison means is adapted to compare~~ a comparator compares this said quotient ∆P/∆V with a predetermined quotient reference value for DHF detection. By adding information about left ventricular end-diastolic pressure the DHF detection can be improved. In a healthy person the end-diastolic volume increases with exercise but shows only a small increase in left atrial pressure. In a person suffering from DHF, who has a more stiff heart muscle, the left ventricular end-diastolic volume changes very little but there is a large increase in left atrial pressure. The quotient ∆P/∆V is consequently a useful quantity for improving the detection of DHF. The difference ∆V is determined by impedance measurements.

~~According to still~~ In other ~~advantageous~~ embodiments of the apparatus according to the invention, a first averaging ~~means is provided to form~~ unit forms an average value of the absolute pressures measured during a ~~plurality~~ of cardiac cycles with ~~said~~ the predetermined workload situation and an average value of the absolute pressures measured during a ~~plurality~~ number of cardiac cycles with the patient in rest, and a second averaging ~~means is provided to form~~ unit forms an average value of ~~said~~ the impedance measured during a ~~plurality~~ number of cardiac cycles with ~~said~~ the predetermined workload situation and an average value of ~~said~~ the impedance measured during a ~~plurality~~ number of cardiac cycles with the patient in rest. In this way the quality of the pressure measurements as well as the impedance measurements are improved.

~~According to~~ In other ~~advantageous~~ embodiments of the apparatus according to the invention a wireless communication ~~means~~ unit is connected to ~~said comparison means~~ the comparator for automatically sending the results of the comparisons with ~~said~~ the reference values to an external

receiver ~~means~~, or a ~~storing means~~ <u>memory</u> is provided for storing the results of the comparisons with ~~said~~ <u>the</u> reference values. Thus if the measured absolute pressure, and possibly also the quotient $\Delta P/\Delta V$, have risen above the associated reference values in a predetermined way<u>,</u> this condition is automatically transmitted to a physician or stored for transmission in connection with a follow-up.

The invention also relates to a pacemaker provided with the apparatus for detecting DHF and <u>a</u> control ~~means for optimizing~~ <u>unit that optimizes</u> pacing therapy depending on the result of the comparisons with the predetermined reference values. The pressure measuring ~~means~~ <u>unit</u> of the apparatus according to the invention then preferably ~~comprises~~ <u>is</u> a pressure sensor connected to the pacemaker, since it can monitor the pulse pressure of its carrier for long periods. This is an advantage since evolvement of DHF is a slow process.

~~An advantageous~~ <u>In an</u> embodiment of the pacemaker according to the invention<u>,</u> ~~comprises~~ a rate responsive sensor ~~for use~~ <u>is used</u> as <u>an</u> activity sensor for determining the workload situation of the patient. Even the pressure sensor of the pacemaker can be used as activity sensor.

~~According to~~ <u>In</u> an ~~advantageous~~ embodiment of the method according to the invention<u>,</u> in a calibration procedure instantaneous values of the left ventricular volume are measured by <u>an</u> ultrasound technique and the relation is established between these measured ventricular volume values and simultaneously measured impedance values. Since the measured impedance depends on the location of the electrodes used, it will vary from patient to patient and therefore such a calibration is required.

As mentioned above the measured difference between left atrial pressure measured in workload and rest situations is compared with a predetermined pressure difference reference value. The reference value for detection of DHF is preferably obtained from measurements on the patient at an early stage of the implantation period of the apparatus or pacemaker. The patient is ~~supposed~~ <u>assumed</u> not to suffer from DHF at the time of implantation. Therefore, ~~according to~~ <u>in</u> an ~~advantageous~~ embodiment of the

method according to the invention, the pressures are measured for different workloads of the patient and for the patient in rest at an early time, when the patient is not suffering from DHF, for determining the pressure difference reference value. Corresponding impedance measurements are preferably

5 also made on the patient at this early stage for determination of the quotient reference value.

~~Brief Description of the Drawings~~

~~To explain the invention in greater detail an embodiment of the invention will now be described with reference to the drawings on which~~

10 ~~figures 1a and 1b are diagrams showing PCWP and LVEDVI respectively as functions of workload for patients having a diastolic dysfunction and control persons not suffering from this dysfunction, figure 2 is a plot of PCWP versus left-ventricular-end-diastolic volume, figure 3 shows a block diagram of an embodiment of a pacemaker according to the invention, figure 4 is a flow~~

15 ~~chart illustrating a procedure for determination of the quotient ΔP/ΔV in an embodiment of the apparatus according to the invention, and figure 5 is a flow chart illustrating an averaging process of the procedure illustrated in figure 4.~~

~~Description of Preferred Embodiments~~

20 Figures 1a and 1b show results of studies on patients having a diastolic dysfunction as explained above. From these figures it ~~appears~~ can be seen that a heart suffering from DHF has another PCWP versus workload behaviour than a normal heart, "Controls" in the figure. The present invention is based on this knowledge since the PCWP is approximately equal to the left

25 atrial pressure LAP.

The detection of DHF by measurements of the absolute left atrial pressure LAP or the pressure in the pulmonary vein can be improved by adding information about left ventricular end-diastolic volume. In a healthy person the end-diastolic volume increases with workload or exercise, whereas

30 the left atrial pressure shows only a small increase. In a person suffering from DHF the left ventricular end-diastolic volume changes vary little but there is a large increase in the left atrial pressure. This is illustrated by ~~figure~~ Figure 2,

which is a diagram from D. W. Kitzman et al, "Exercise Intolerance in Patients with Heart Failure and Preserved Left Ventricular Systolic Function: Failure of the Frank-Starling Mechanism", J. Am. Coll. Cardiol., 17:1065-1072, 1991, plotting PCWP versus left ventricular end-diastolic volume. The open boxes

5   in the figure indicate the direction of change from rest to exercise or workload for patients with DHF, and the solid boxes illustrate the corresponding direction of change for normal control persons. The shift upwards in the diagram for ~~sick~~ <u>non-healthy</u> patients should be noted.

The left ventricular end-diastolic volume is preferably determined by

10   measurements of the electric impedance between e.g. a left ventricular electrode, normally placed in a coronary vein, and an electrode in right ventricle, right atrium or any other place in or on the heart, such that most of the variations in the measured impedance derive from variations in the left ventricular volume, as will be described below.

15   The detection and measurement of degree of DHF can be improved by studying the quotient $\Delta P/\Delta V$. ΔP denotes the difference between left atrial pressure measured in the workload and rest situations and ΔV the difference in the end-diastolic ventricular volume, obtained by the impedances measurements, for the predetermined workload situation and for the patient in

20   rest, as explained above.

The quantity ΔV, and consequently the quotient $\Delta P/\Delta V$, is depending on the positions of the electrodes, used for the impedance measurements. These quantities will therefore vary from patient to patient. Thus some kind of calibration is needed.

25   The left ventricular volume varies during a cardiac cycle. The instantaneous volume can be measured by e.g. ultrasound technique. By simultaneously measuring corresponding impedance values a relation can be established between measured impedance values and left ventricular volume. The measured pressure difference ΔP can be directly obtained since the

30   sensitivity of the pressure transducer is set by the manufacturer.

The reference value for the quotient $\Delta P/\Delta V$ for detection of DHF can be set from common knowledge about physiological properties during the

progression of DHF. In the same way the severity of the progression of DHF can be followed.

Figure 3 is a block diagram of an embodiment of a pacemaker according to the invention, including a pressure sensor 2, sensitive to the

5   pressure in left atrium, LAP, of a patient's heart 4. The atmospheric pressure and the pressure from blood volumes above the sensor also contribute to LAP. To compensate for this a sensor 6 is also provided for measuring the pressure in the right atrium or in vena cava. This compensation pressure is denoted by Pref.

10   A measurement value correlated to left ventricular volume changes ΔV is obtained by measuring the impedance Z between an electrode 8 in or attached to the left ventricle and an electrode 10 in the right ventricle. The parameters in question are measured in the diastasis phase just before the atrial contribution to the left ventricular filling. ~~To do~~ For this purpose a timer

15   can be used, starting at the preceding contraction. Alternatively P-waves can be sensed by an electrode 12 implanted in the right atrium of the heart 4 for starting the measurement. Parameter values measured during a period preceding the atrial contraction are stored in a ring buffer. This procedure will be described below with reference to ~~figure~~ Figure 4.

20   The pacemaker in ~~figure~~ Figure 3 ~~comprises~~ has ordinary circuits 14 for IEGM sensing and stimulation. It also comprises circuitry 16 for measuring the impedance Z between implanted electrodes 8, 10 as mentioned above. To determine volume changes of heart chambers by impedance measurements between electrodes implanted in the heart is per se previously

25   known from e.g. EP 1 384 492. Such impedance measuring circuitry is also known from respiration activity measuring pacemakers.

The pacemaker illustrated in figure 3 also contains a unit 20 for measuring activity or workload of the patient by means of an activity or workload sensor 22. An ordinary microprocessor with supporting circuits 18

30   are provided for calculation and signal processing explained in the following with reference to ~~figures~~ Figures 4 and 5. Sensed Pref and LAP signals are ~~digitized~~ digitized in A/D- converters 24 and 26 respectively before supplied to

the microprocessor and supporting circuits 18. Data related to sensing and pacing, the measured impedance Z, and the activity or workload Act of the patient are supplied to the microprocessor and its supporting circuits 18 as well.

5   For communication with and transfer of data to external ~~equipments~~ equipment the pacemaker is provided with a telemetry ~~means which are~~ unit that is not shown in ~~figure~~ Figure 3.

Figure 4 illustrates the determination of the quotient $\Delta P/\Delta V$. Since DHF evolves slowly, necessary measurements may be performed regularly,

10   preferably with long intervals, for a long time. A timer is therefore provided, block 28 in ~~figure~~ Figure 4, and the process illustrated in the figure, is started by a check of status of the timer 28, block 30. The timer 28 may be set to e.g. hours, days or weeks.

As soon as the timer 28 has counted down to zero the measurements

15   of LAP, Pref, the impedance Z corresponding to left ventricular volume, and the activity or workload Act of the patient are started, block 32 in ~~figure~~ Figure 4. It should be noted that the impedance is inversely correlated to the volume, but since the impedance variations are small and superimposed on a larger absolute impedance, impedance measurements are anyhow suitable

20   for this purpose.

Measured data are stored in a ring buffer with n positions and large enough to store data from pre-atrial loading of the left ventricle, block 34

As soon as a P-wave is detected, block 36, stored values of LAP, Pref, Z and Act are collected from a memory position n samples before the point of

25   the P-wave detection. The number n depends on several circumstances, like the shape of the P-wave, the filter in the P-wave amplifier, and the position of the right atrial electrode 12. In this way data are obtained from a point of time immediately before a noticeable change of the ventricular volume caused by the atrial contribution.

30   After this collection of parameter values average values of corresponding parameters, taken over several cardiac cycles, are created, block 38 in ~~figure~~ Figure 4 and block 40 in ~~figure~~ Figure 5. The average value

creating process is illustrated in greater detail in ~~figure~~ 5. The purpose of the average creation is to improve the quality of data.

The contribution from the atrium to the ventricular filling should not be part of the left ventricular volume measured in this procedure, as explained above. Thus data are extracted from a storage position n samples before the latest sample, block 42 in ~~figure~~ Figure 5, to avoid atrial contribution to the ventricular filling. Stored average values of LAP, Pref, Z and Act from previous heart beats are used, block 44, to produce a floating mean value by adding a fraction 1/k of the present value to the already existing "old" average value, according to the equation

$$\text{New\_Average\_Value} = \frac{Value + (k-1) \bullet Old\_Average\_Value}{k}$$

where "Value" means the present value.

This process is performed for each of the parameters LAP, Pref, Z and Act, block 46, and the new average values are stored, block 48 in ~~figure~~ Figure 5. Block 46 contains corresponding equations for creating new average values of each of the parameters LAP, Pref, Z and Act, "avg" denoting "average".

~~It is then returned~~ A return is then made, block 50, to the main procedure illustrated in ~~figure~~ Figure 3, where the next step consists in subtraction of Pref from LAP to obtain the corrected LAP value LAP$_r$ as discussed above. Thus,

$$\text{LAP}_r = \text{LAP} - \text{Pref}$$

block 52 in ~~figure~~ Figure 4. The corrected value LAP$_r$ is then used to create the quotient $\Delta P / \Delta V$, block 54, store it in a memory, block 55, and compare the quotient $\Delta P / \Delta V$ with a reference value for subsequent actions, block 56.

For this procedure the parameter values are preferably stored in an organized way, in this case in a table, see Table 1 below. This table is set up in a memory. The parameters are measured over time for different workload levels of the patient, and this is used to increase the number of available measurements to be used and to improve the results. When average values

over several cardiac cycles of the parameters have been obtained LAP_r and Z are stored in a table according to how actual activity or workload level fits the activity or workload intervals in the table. The following Table 1 shows an example of how ~~to do~~ this <u>can be done</u>.

5

Activity interval	LAP_r	Z	Parameters set
Act_1 to Act_2	data	data	1
Act_2 to Act_3	no data	no data	0
...	...	...	...
Act_{n-1} to Act_n	data	data	1
N			Sum of above

Table 1

The table will contain very few data at the beginning of the use of the apparatus according to the invention. With every entry into this process data will be filled in the table, either directly or via an averaging process if data already exist in memory positions in question. An "1" in column "Parameters set" indicates that a true parameter has been obtained and stored in the table. An "O" indicates the opposite.

In Table 1 "N" denotes the number of activity or workload levels for which averaged parameter values have been stored and over which the quotient $\Delta P/\Delta V$ has to be determined.

For determining the quotient $\Delta P/\Delta V$, ΔP is first created for each indicated activity or workload interval in the table. All pressure data are referenced to the pressure for the patient in rest, Prest. The corresponding process is performed for ΔV. Since N activity or workload intervals are indicated as active in Table 1, N – 1 quotients $K_i = \Delta P_i/\Delta V_i$; are obtained. The average value of the K_i – values is returned, and $K_{avg} = (\Sigma K_i)/(N-1)$ is obtained. Thus the quotient K_{avg} is calculated.

The quotient K_{avg} is then compared to a predetermined reference value, preferably established and stored at the beginning of the use of the apparatus according to the invention (when the patient possibly were not yet suffering from DHF). By storing subsequent quotients K_{avg} together with associated time marks the evolvement of the degree of DHF can be followed

over time. A test can be set up to test whether the quotient has passed a certain limit for starting an automatic transmission of the DHF status of the patient to the physician. This message is transferred by means of the telemetry link of the apparatus according to the invention.

5   Although modifications and changes may be suggested by those skilled in the art, it is the invention of the inventors to embody within the patent warranted heron all changes and modifications as reasonably and properly come within the scope of their contribution to the art.

[[_____]]

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